Topographical & Digital Imagery Survey for Highway Alignment Project using LiDAR Technology

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ABSTRACT

This project was the first use worldwide of the newest LiDAR system DVG-Helix, developed jointly by Malaysians and Canadians, for a Road Alignment survey. The system was proposed as it was much faster, cheaper and as a whole, much more accurate than conventional survey methods. Also, it allowed for a wider range of alignment options to be studied for more cost-effective and faster construction while minimizing the environmental impacts of such works. In fact, the East Coast Expressway Alignment was substantially changed midway through the design stage. Only DVG-Helix was able to do the re-alignment survey quickly, allowing for prompt changes in design, such that there was little change to the total project schedule as demanded by the client. This would not have been possible by conventional survey methods. This paper also compares LiDAR survey with conventional ground survey in terms of cost, time and accuracy.

1. INTRODUCTION

1.1 Overview of Road Alignment Planning and Design

One of the most important requirements for good road alignment planning and design is high accuracy and detailed topographical and features information. For most projects, this would be balanced against cost and duration of the project. To acquire this information, there are many survey techniques available such as: land survey, aerial photogrammetry, satellite imagery, radar and LiDAR survey. Table 1 describes the characteristics of the various survey techniques. For road alignment planning and design, the most important characteristics would be spatial/pixel resolution, position and height accuracy as they are a measure of the accuracy and detail of the terrain and features information provided by that survey technique.

1.2 Summary of available Survey Techniques

Land survey techniques involve taking measurements on site using total stations and similar equipment and are commonly used for alignment planning and design but being human resource intensive, are prone to human error and are very time-consuming, especially for large areas. For highly vegetated, hilly and/or remote areas, accessibility to the site can be especially challenging for land survey techniques. Poor weather conditions and land ownership issues also can be problematic for land surveyors. The long alignments required for roads tend to create errors in land surveying due to the long traverses and difficulties of merging survey data from different survey teams and areas.

Photogrammetry was the first remote sensing technique and entails taking aerial photographs of the area which then are geo-and-orthorectified using either the measured locations of various identified features in the image or the parameters at which the image is taken. However, the position and height accuracy from photogrammetry are very dependant on the geo-and-orthorectification process and type of terrain. Furthermore, photogrammetry is unable to measure ground levels under vegetation and estimate them using an average tree height, which can produce errors in excess of 10m. Thus photogrammetry is only applicable for coarse alignment analysis. Also, weather conditions such as clouds can affect the collection time of photogrammetry as the survey waits for months for clear cloudless days to acquire the imagery.

Other remote sensing survey techniques are satellite imagery, of which there are several types available such as: Ikonos, Spot 5, QuickBird, Landsat etc. However, like aerial photogrammetry, ground levels under vegetation are estimated using average tree heights which may produce large errors while cloud cover would prevent information capture such that in some areas, satellite imagery may not be readily available for years. As shown in Table 1, the positional and height accuracy is low such that it is only suitable for coarse alignment design.

Table 1: Characteristics of Different Survey Techniques

SURVEY TECHNIQUE	SPATIAL/PIXEL RESOLUTION	SPECTRAL RESOLUTION	TEMPORAL RESOLUTION (DAYS)	FOOTPRINT (km x km)	POSITION ACCURACY	HEIGHT ACCURACY
LANDSAT7	15 m	7 BANDS	16	185 x 185	15 m	15 m
IKONOS	1 m	3 BANDS	3.5 –5	11 x 11	0.5 m	5 m
QUICKBIRD2	0.62 m	3 BANDS	1.5- 4	16.5 x 16.5	0.9 m	1.2 m
ASTER	VNIR: 15 m IR: 30-90 m	14 BANDS	IN SPACE SHUTTLE	VARIABLE	15 m	30 m
OBRVIEW4	1m	4 BANDS	3	8 x 8	1 m	1.7 m
SPOT 5 (A,B)	2.5 m 20 m (Mid IR)	4 BANDS	1- 4	60 x 60	10 m	2.5 m
AERIAL PHOTO	Up to 0.15 m	VISIBLE BAND	ON DEMAND	2 x 2 at 3,000 m	15m to 30m	15m to 30m
RADAR	10m to 100m	C BANDS (HH)	24	35 X 500	30m	30m
LAND SURVEY	ON DEMAND	NA	NA	NA	0.005 m	0.003 m
AIRBORNE LiDAR	2.2m to 0.2m points/m^2	NIR BAND	ON DEMAND	VERY DENSE	0.5 m (OPEN AREA) ±1 m (DENSE JUNGLE)	0.15 m (OPEN AREA) 0.3 m (DENSE JUNGLE)

Radar is an active remote sensing technique which is able to operate both during the day and at night but this technology does not identify features and the elevation accuracy is around 10 m and so only suitable for very preliminary alignment design.

LiDAR or (Light Detection and Ranging) is an active remote sensing technology that is able to produce high-density and high accuracy data for planning and design work. While LiDAR data can be acquired during the day or night, LiDAR systems generally collect imagery at the same time so day time collection is usual. LiDAR is particularly effective in hilly, highly vegetated and/or remote areas as it is the only survey technique to accurately measure ground levels directly. Satellite and aerial photogrammetry interpolate ground levels using tree height estimates which can cause gross inaccuracies, while Radar is inherently less accurate than

LiDAR and land survey has site inaccessibility issues. LiDAR measurements are in digital format so it is free from the conversion-to-digital error engendered by land survey and other techniques and easily utilised by MOSS and other software.

1.3 Road Alignment Planning and Design

Once the survey data has been collected, it is analysed by the planning and design engineers for the best alignment. Several road analysis software are available for this but MOSS was chosen for this project as it uses 3D data "strings" to model surface features as opposed to the traditional cross section template method used by some other software which would interpolate between the cross sections and therefore be less accurate.

Before MOSS and other similar software, this analysis would be done by hand using charting techniques and gross estimates for earthworks. The time and effort this would take would entail only 1 alignment being considered. However, MOSS uses the survey data to precisely calculate the required earthworks for a given alignment such that corresponding calculations for costs and time are much closer to the actual values for construction.

Land survey data generally consists of one alignment with cross sections taken every 100m so MOSS would interpolate between cross sections, leading to less precise earthworks calculations. Photogrammetry, Satellite and Radar elevation measurements are coarse, also leading to less precise earthworks calculations. LiDAR, though, generally collects a wide corridor of high accuracy and density elevation data, between 1 to 10km in width, such that MOSS is able to precisely calculate earthworks for several proposed alignments very quickly. Thus, only using LIDAR data with MOSS software allows for very accurate construction costs and time analysis of several road alignments in a very short time. It also allows for cut and fill earthworks to be balanced for sectional completion.

1.4 LiDAR

LiDAR is an acronym for Light Detection and Ranging and is a laser mapping technique for measuring distance. It works by sending laser pulses of near-infrared wavelength towards objects and measuring the time for the reflective return of energy, which allows for the distance between the object and laser sensor to be calculated with the constant speed of light. LiDAR systems will integrate with a Global Positioning System (GPS) to know the position of the laser and an Inertial Measurement Unit (IMU) to know the angle the laser is pointed at, such that the object can be precisely mapped in 3 dimensions. For rapid mapping of areas, LiDAR systems are mounted on aircraft and may emit between 30,000 to 250,000 pulses per second; thus a dense point cloud of the survey area is produced. As LiDAR is collected in WGS84, it then needs to be converted to local coordinates using the local GEOID model.

However, raw LiDAR point cloud data includes points from vegetation, buildings and other objects in addition to the ground points. Thus, it must be processed and classified into the various feature categories to allow production of a “Bare Earth” model of the area, feature identification and other uses. For road alignment, the Bare Earth model or Digital Terrain Model (DTM) is used by MOSS for earthworks calculation while the Digital Elevation Model (DEM) allows for feature identification which provides further information of the area for the consideration of their effects on the proposed road alignment.

LiDAR systems generally include still or video cameras for simultaneous capture of imagery data. The frames may then be ortho-rectified and mosaiced using the LiDAR, GPS and IMU data of the system, such that better visual interpretation of features is possible.

There are several types of LiDAR system available worldwide and for this East Coast Expressway project, DVG-Helix was used, a system which was designed, built and operated by Ground Data Solutions Sdn Bhd. (GDS) a Malaysia company in partnership with LiDAR Services International (LSI) of Canada.

2. Project

2.1 Study Area

GDS carried out the airborne LiDAR survey for East Coast Expressway Phase 2 (ECE 2) project, which is located on the East coast of Peninsular Malaysia. The corridor was approximately 200.5km long and 1.5km wide and ran from Kg Jabur to Kuala Berang. The data acquisition took about 22days (from 23 August 2004 to 14 September 2004) and the final DTM and DEM was processed at site for delivery 7 days after data acquisition was completed.

However, in 2005 the East Coast Expressway alignment was changed to meet changing social requirements and to better serve local communities by the coastline while the project completion date was largely maintained; thus another airborne LiDAR survey was carried out based on the re-aligned corridor. The re-aligned corridor was from Ceneh to Bukit Besi and 105Km long and 1.5Km wide. The acquisition was completed in 10days and the DTM and DEM delivered a week after data acquisition. No other survey method could have been implemented without a severe impact on the project in terms of cost and time.

The area consists of various terrain conditions including oil palm plantation, rubber plantation, dense forest, open areas, urban areas, flat and undulating. There were also some major urban and industry areas located within the corridor such as Jabur, Ceneh, AMBS, Paka, Bukit Besi, Dungun, Kuantan, Ajil, Kerteh, Kuala Berang and Kuala Terengganu.

2.2 Project Description

The main objective of these two survey projects was to produce the topographical and features map of the areas using airborne LiDAR technology for input into MOSS design software for the highway alignment planning and design. Table 2a, 2b, 2c and 2d provide more details on the project.

Table 2a: LiDAR system specifications

Description	Type
Scanning Laser 60^o	Riegl LMS-Q140
Inertial Measurement Unit (IMU)	Germany (INAV-FMS)
Video Camera	Sony TRV-900
GPS on board helicopter	Novatel DL Propak receiver
GPS on the ground	Leica System 500
Profiling Laser	Infrared of wavelength (904nm)

Table 2b: LiDAR Survey Operation Specifications

Description	Type
Flying height	250m Above Ground Level
Aircraft	Bell206B
Flying Speed	96kph to100kph
Laser swath width	289m

Table 2c: LiDAR Survey Achieved Data Characteristics

Type	Description
Lidar density	2 million points in 1km x 1km (2 points/m^2)
Lidar points hitting ground	more than 200,000 points in 1km x 1km (0.2 points/ m^2)
Average ground points spacing	2.2m
Laser swath width	289m
Image Resolution	0.2m

Table 2d: LiDAR Survey Project Specifications

Project	Deliverables	Acquisition Duration	Total Duration	Cost (Malaysian Ringgit)
ECE (Phase 2) (2004) 200.5km x 1km	i) 1m interval contours in MOSS GENIO format ii) DTM&DEM in ASCII format iii) High resolution ortho rectified mosaic images (0.2m) iv) Digitized features and convert to MOSS GENIO format	22 days	89 days	RM 1,436,754.37
ECE (Phase 2) re-alignment (2005) 105km x 1km	i) 1m interval contours in MOSS GENIO format ii) DTM&DEM in ASCII format iii) High resolution ortho rectified mosaic images (0.2m) iv) Digitized features and convert to MOSS GENIO format	10 days	40days	RM 797,370.18

The DVG-Helix LiDAR system was installed in a Jet Ranger Bell206B helicopter. The data was acquired at 250m above ground level for up to 5 hours a day.

The data was collected in WGS84 latitude, longitude and ellipsoidal height and then transformed to Terengganu Cassini projection with the vertical coordinates based on the adjusted Mean Sea Level (MSL) height as described here. The WGS84 datum was used in conjunction with the EGM96 geoid model (the best available undulation model for the area at the time of the survey) to convert from ellipsoidal height to MSL height.

The raw LiDAR data was processed with special in-house programs where the data from the LiDAR sensor, GPS and IMU was combined to produce the point clouds. The point clouds were compared and checked with the calibration passes before generation of the final point clouds. TerraScan and TerraModeler were used to classify the LiDAR data automatically, followed by final verification by experienced LiDAR personnel. Then 1m contours were generated. High-resolution digital imagery with their perspective centre coordinate, derived from the LiDAR, GPS and IMU data, was collected simultaneously with LiDAR data. These images were ortho-rectified and mosaiced to the same projection with the generated contours. Figures 1 and 2 show the sample output for this project.

Figure 1: Ortho rectified Image overlay with contour

Figure 2: Isometric view of the point cloud

Features relevant to the alignment planning and design were vectorized using the ortho rectified images and then the vectorized features and the contours were converted to MOSS format for the earthworks calculation and further analysis of the road alignments. Three (3) alignments were proposed and their construction costs and time and other effects were reviewed to determine the best alignment. Figure 3 shows some sample output from MOSS software.

Similarly, 105km of the corridor was later resurveyed and reanalyzed when there was a major change to bring the highway nearer the coast from the original inland alignment.

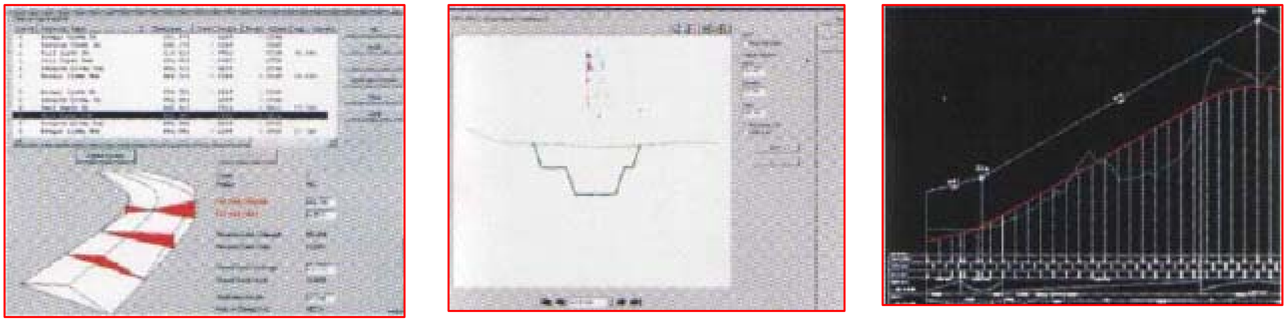

Figure 3: Sample output from Moss software

2.3 Land Survey Estimation

The time and cost required to use land survey techniques for this project was estimated based on our previous experience and using the standard land survey fee schedule as prepared by the Ministry of Finance Malaysia (Jadual Fee Ukur Kejuruteraan 2001). Terrain condition was estimated using a few series of topographical maps (Series L7010 Number 37, 38, 49, 50, 61, 62, 72, 73 & 83) produced by JUPEM (Department of Survey and Mapping Malaysia). For survey duration, 1 team was estimated to survey 200m per day with 6 teams being mobilized for the projects. For final mapping, 6 teams would complete 6.5km per day. Table 4 details the estimated times and costs for using land survey to map East Cost Expressway Phase 2 project.

Table 4: Land Survey Project Specifications

Project	Deliverables	Total Duration	Cost (Malaysian Ringgit)
ECE (Phase 2) (2004) 200.5km x 60m	i) Route survey and profiling a) Flat and undulating b) Hilly/swampy/built-up area ii) Set-out and mark reserve 60m width iii) Monumenting 1. With concreting a) Accessible b) Not accessible 2. Without concreting a) Accessible b) Not accessible iv) Strip Survey a) Flat and undulating b) Hilly/built-up v) GPS Station at 10km Interval	203 days	**RM 2,397,417.83**

ECE (Phase 2) re-alignment (2005) 105km x 60m	i) Route survey and profiling a) Flat and undulating b) Hilly/swampy/built-up area ii) Set-out and mark reserve 60m width iii) Monumenting 1. With concreting a) Accessible b) Not accessible 2. Without concreting a) Accessible b) Not accessible iv) Strip Survey a) Flat and undulating b) Hilly/built-up v) GPS Station at 10km Interval	112 days	RM **1,320,959.38**

3. Results and Analysis

3.1 Accuracy

An analysis of elevation data from LiDAR and Land Survey data for a sample area in the project showed high agreement. The deviation of the data was between 0.054m to 0.196m at 85% confidence level and 0.06m to 0.233m at 95% confidence level. In many ways, the LiDAR data could be deemed to be more accurate than the land survey data because there were many errors in the land survey, where feature levels, such as invert levels, culverts, sumps, buildings, head walls and road signages showed inconsistencies, which would cause gross inaccuracies in any earthworks calculations. Also, the LiDAR data was measured as one complete area with one datum, whereas the land survey data used different datums in different areas, leading to inconsistencies when tying all the areas together.

As the LiDAR data provided ground points at an average spacing of 2.2m, the earthworks calculations and thus cost and time analysis for the road alignment would be very precise compared to those from land survey data where the engineer must interpolate between the cross sections of 100m interval. This is particularly advantageous for the MOSS 3D strings modelling method, allowing for very exact earthworks calculations.

3.2 Cost

LiDAR cost RM1,436,754.37 to map the 200.5km by 1.5km corridor while Land Survey would have cost RM2,397,417.83 for mapping just 200.5km by 60m. For 105km by 1.5km corridor, LiDAR cost RM797,370.18 compared to Land Survey's cost of RM1,320,959.38 for 105km by 60m. Comparing just survey costs, there was a saving of 40.1% for the 200.5km length and 39.6% for the 105km length.

However, LiDAR mapped for a 1.5km corridor and included imagery allowing for cost analysis of multiple alignments whereas Land Survey would have mapped only 60m width with cross

sections every 100m for 1 alignment. Thus, LiDAR with MOSS allowed for much more accurate earthworks calculations of several alignments compared to the interpolated estimates for one alignment from Land Survey, so LiDAR and MOSS optimised the route alignment for far greater construction costs savings.

There may also have be substantial savings in land acquisition costs as LiDAR survey is very discreet compared to land survey and a time stamped image of the area was produced for tree counting and other compensation calculations. However, in Malaysia and other countries, land boundaries are certified by land surveyors so the final land acquisition plan must be marked out and mapped by a licensed land surveyor. This would generally be done during the pegging out required for construction and again would be done by a certified land surveyor.

3.3 Duration Comparison between LiDAR and Land Survey

LiDAR provided the contours of the 200.5km by 1.5km area in 29 days and final mapping in less than 13 weeks while land survey would have taken 29 weeks at best. Similarly, for 105km length, LiDAR submitted contours in 17 days and final mapping in less than 6 weeks, while land survey would have taken 16 weeks. Land survey is subject to weather conditions and site accessibility problems so the estimates here are very optimistic. Thus LiDAR survey duration is a fraction of land survey duration, which was the main reason why LiDAR was used for this project, which had very tight deadlines for construction completion and very late major changes in the alignment.

LiDAR data is quickly converted into MOSS GENIO format for rapid earthworks analysis so the design period is short, compared to conventional methods. The multiple alignments are also reviewed for construction time so it is minimised too.

3.4 Comparison between LiDAR and Land Survey

LiDAR is especially valuable in environmentally or socially sensitive areas as it is a totally unintrusive form of surveying unlike land surveys that would require surveyors to have ground access to these areas and the high likelihood of vegetation clearing to ensure line of sight for the survey instruments. LiDAR in MOSS software can balance the cut and fill required so environmental impact during construction is decreased too. The LiDAR imagery allows for identification of environmentally or socially sensitive features such as squatter settlements, protected tree species, etc for consideration of the engineer.

4. Conclusion

Using LiDAR survey data in MOSS software for road alignment planning design, allows for detailed analysis for multiple alignments such that construction costs, time and environmental and social impact can be minimised. For the East Coast Expressway Phase 2 project, LiDAR was also shown to cost less than Land Survey while providing much more information in terms of area, density of measurements and feature identification. LiDAR cannot replace Land Survey as a licensed land surveyor is required for pegging and land acquisition before construction but using LiDAR for route selection can have substantial savings on the cost of the project. Satellite, Radar and Aerial Photogrammetry can be cheaper than LiDAR, especially when recent archive data is available but they are not accurate enough for detailed analysis so they are only suitable for macro studies.

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